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Food waste generation and composition from Danish households

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Abstract

Sustainable solutions for reduction of food waste require good understanding of food waste generation and composition, including avoidable and unavoidable food waste. We analysed 12 tonnes of residual household waste collected from 1474 households, without source segregation of organic waste. Food waste was divided into six fractions according to avoidability, suitability for home composting and whether or not the food waste was cooked, prepared or had been served at within the household. The results showed that the residual household waste generation rate was 434±18 kg per household per year, of which 183±10 kg per year was food waste. Unavoidable food waste amounted to 80±6 kg per household per year, and avoidable food waste was 103±9 kg per household per year. The mass of food waste was influenced significantly by the number of occupants per household (household size) and the housing type. The results also indicated that avoidable food waste occurred in 97% of the households, suggesting that a most of Danish households could avoid or at least reduce food waste generation. Moreover, food waste including avoidable and unavoidable was more likely to be found in houses containing more than one person than households containing only one person.

Keywords:

Household food waste

Avoidable food waste

Unavoidable food waste

Food waste generation

Bootstrap and confidence interval

1 Introduction

Food production and distribution exert increasing pressure on natural resources such as land, water and energy; however, one-third of the total mass of food produced is either wasted or lost (Gustavsson et al., 2011). Thus, the resolution of the European Parliament on resource efficiency calls on the European Union (EU) Commission (EC) to set a target to reduce by at least 30% the mass of food wastage in EU member states by 2020 (European Parliament, 2015). Food is wasted and lost throughout the food supply chain. In EU member states, food waste from households is relatively higher compared to other parts of the food supply chain (Brautigam et al., 2014; Monier et al., 2010). For this reason, reducing food waste from households may contribute significantly to meeting the reduction target, as well as provide financial and energy savings (Dana, 2012; WRAP, 2009). Initiatives and efforts to change household behaviours related to food waste require a detailed understanding of the quantities and composition of what is discarded. However, although previous studies have measured food waste occurring throughout the food supply chain as well as from households, most of these studies have provided only average data, making the description of the food waste generation between households impossible. Moreover, existing studies have diverse scopes and differ in their definitions, metrics (e.g. mass, calories) and measurement protocols (e.g. sampling) (HLPE, 2014), making the comparison of food waste data between studies challenging. Therefore, there is a need to estimate accurately and consistently the food waste generation and composition from households (Halloran et al., 2014).

The lack of a consensus methodology for food waste data collection has led to the development of various food waste estimation methods, such as questionnaire surveys (Abeliotis et al., 2014; Parizeau et al., 2014, Tucker and Farrelly, 2015), kitchen diaries (Langley et al., 2010; Silvennoinen et al., 2014; Williams et al., 2012) and literature reviews based on waste statistics from public authorities (Beretta et al., 2013; Brautigam et al., 2014; Gustavsson et al., 2011; Monier et al., 2010). The reliability and accuracy of data from these methods may be hampered by various limitations and inherent errors (Hallström and Börjesson, 2013). First, kitchen diaries and questionnaire surveys require a good memory and the honesty of the participants, which can hardly be documented (Hallström and Börjesson, 2013). Second, a general ethical consideration associated with food can influence the response of participants (Fessler and Navarrete, 2003). As an example, Parizeau et al. (2014) reported that households in Canada overestimated home cooking because it is less socially acceptable “to be identified as someone who does not cook but relies on pre-packaged foods." Similarly, Quested et al. (2011) estimated that food waste generation data from kitchen diaries were 40% lower than when based on waste stream analysis in the UK. Third, national waste statistics may be prone to significant uncertainties, due to (i) varying definitions of food waste and (ii) the calculation methods and assumptions applied (Brautigam et al., 2014; HLPE, 2014). Therefore, waste stream analysis is recommended to obtain reliable data on food waste generation and composition (Dahlén and Lagerkvist, 2008; Monier et al., 2010).

The disadvantage of the waste stream analysis is that only food waste entering the municipal waste stream is analysed. Thus, the waste steam analysis may exclude the food waste that is fed to animals, home composted or disposed via the sewer system (WRAP, 2009). Langley et al. (2010) argued that the waste stream analysis characterises waste that age could affect the degradation of some food products making their separation and identification awkward. However, several methods for characterisation of municipal solid waste suggested to analyse at least one full week of waste because the waste generation during weekends may differ compared to weekdays (Dahlén and Lagerkvist, 2008). The degradation of waste including food waste is significantly minimised when the waste is sorted within a week from the sampling day (European

Commission, 2004; Nordtest, 1995), which has been confirmed by practical experience (Edjabou et al., 2015).

An additional limitation of existing food waste studies is that they focus mainly on avoidable food waste (Halloran et al., 2014). To provide a consistent basis for new initiatives targeting households, the detailed relationship between both unavoidable and avoidable food waste needed to be understood (Halloran et al., 2014).

A number of studies on this subject have found a correlation between the mass of avoidable food waste and the number of occupants per household. However, these studies had relatively small sample sizes (Langley et al., 2010; Parizeau et al., 2014). Moreover, issues such as uncertainty related to the influence of household size as well as geographical and periodic variations on avoidable and unavoidable food waste have not been systematically investigated. Consequently, the statistical uncertainties related to the generation of food waste and potential influencing factors are poorly documented. The uncertainty related to temporal variation could be reduced by sampling in different periods (Dahlén and Lagerkvist, 2008).

The prevention of food waste has the highest environmental benefits (Gentil et al., 2011). However, a biological treatment of food waste (e.g. home composting, central composting, anaerobic digestion) that cannot be reduced or prevented (e.g. unavoidable food waste) generates various benefits, such as: (1) reduction of environmental impacts such as emission of greenhouse gases, surface and groundwater contamination, and soil pollution , (2) generation of nutrients that will be returned to food production system, (3) production of biogas (Andersen et al., 2010; Raven and Gregersen, 2007; WRAP, 2009), and (4) financial incentives due to high taxes on landfilling and incineration (Danish Government, 2013).

Currently, one of the challenges facing biogas plants (e.g. in Denmark) is a reliable availability of organic material (Raven and Gregersen, 2007). Therefore, availability of food waste constitutes one of the key parameters for feasible economic operation of biogas plants (Raven and Gregersen, 2007). Generally, the availability of waste materials from household are also considered for planning of waste source-segregation systems, and development of collection schemes (Nilsson and Christensen, 2010).The availability of food waste can be estimated by analysing the occurrence of food waste from households (US EPA, 2002). Despite the importance of these data, they were not attempts to analyse food waste occurrence from households, thereby hindering our ability to accurately map resources and develop food waste treatment technologies.

The overall objective of this study was to estimate the occurrence, the mass, and composition of discarded food fractions from Danish households. The study also aimed at evaluating and estimating the influence of the following factors: (1) geographical variations (city, municipalities and region), (2) periodic variations, and (3) household size, on the mass and the occurrence of individual food waste fractions.

2-Materials and methods

2.1 Definitions and classification of food waste

In this study, *food waste* includes food, drinks and beverages that are avoidable and unavoidable (FUSIONS, 2014; WRAP, 2009). We applied the food waste classification described by Edjabou et al. (2015), WRAP (2009) and FUSIONS (2014). Initially, food waste was subdivided into animal-derived products and vegetable products. Vegetable food waste estimates the potential mass of food waste from households that could be home composted, provided that in home composting schemes, animal-derived may be, excluded because of the risk of attracting flies, rats and other pests as well as undesired odours (Christensen and Matsufuji, 2010). The two food waste fractions (animal-derived and vegetable) were further grouped into avoidable and unavoidable food waste (FUSIONS, 2014; Koivupuro et al., 2012; Lebersorger and Schneider, 2011; WRAP, 2009). *Unavoidable food waste* is defined as “food that is not and has not been edible under normal circumstances”(WRAP, 2009), e.g. bones, carcasses, egg shells, peels, fruit skin, apple cores, coffee grounds, etc. (Table 1 & Table SM 1), while *avoidable food waste* refers to edible food that could have been eaten but instead is disposed off regardless of the reason (FUSIONS, 2014). Finally, avoidable food waste was split into two further fractions. The first covered “food and drinks that have been cooked, prepared or served in the home”(WRAP, 2009), characterised as *avoidable processed food waste*, while the second covered “purchased food that has been discarded” (WRAP, 2009) such as discarded food that has not been cooked, prepared or served as a meal (*avoidable unprocessed food waste).* As a result, we had six detailed fractions: (1) “avoidable unprocessed vegetable food waste” (AUVFW), (2) “avoidable processed vegetable food waste” (APVFW), (3) “unavoidable vegetable food waste” (UVFW), (4) “avoidable unprocessed animal-derived food waste” (AUAFW), (5) “avoidable processed animal-derived food waste” (APAFW) and (6) “unavoidable animal-derived food waste” (UAFW) (Table 1 and Table SM 1). Table 1 provides an overview of what was included in these categories, while Table SM 1 shows how they were grouped. For comparison purposes, these categories were grouped into 11 food categories adapted from WRAP (2009) and Lebersorger and Schneider (2011), as shown in Table 1 (2^{nd} column) and in

Table SM 2. We differentiated between avoidable food waste and unavoidable food waste based on the general food habit and tradition in this study area. Thus, this classification may change according to the food habit of the area (e.g. country, region) with respect to culture, tradition, and religion. The reason is there are some “food that some people eat and others do not” (Beretta et al., 2013; FUSIONS, 2014; WRAP, 2009)

2.2 Study area

Residual household waste was sampled in five municipalities in Denmark, namely Gladsaxe, Helsingør, Odense, Viborg and Kolding, as shown in Table 2. In these municipalities, food waste was neither source-segregated nor accepted at recycling stations. Instead, along with other residual waste (e.g. tissues papers, nappies, beverage cartons, plastic film, metal cans, etc.), it was disposed of in residual waste bins. However, gardening waste, paper, board, glass, waste electrical and electronic equipment (WEEE) and batteries, household hazardous waste and bulky waste were source-segregated.

Residual household waste management and collection varied according to housing type. In single-family house areas, an individual waste bin for each house was used to collect residual waste, whereas, in multi-family areas, people living in the same apartment block used a joint full-service collection point system, with many of them sharing the same waste bin. In single-family house areas, residual waste bins consisted of paper sacks and plastic bags between 110 and 240 L in capacity, whereas in the multi-family house areas, wheeled containers of 400 to 750 L were used. Residual household waste was collected every week in the multi-family house areas and every two weeks in the single-family house areas. This difference between the two types of household explains the waste sampling and sorting procedures applied in this study.

To encourage home composting, especially in the single-family house areas, municipal authorities have provided home composting units to those interested in doing it. Additionally, the municipality of Viborg has provided these composters for free, whereas other municipalities charge a fee.

2.3 Sampling of residual household waste

Table 2 provides an overview of the waste sampling campaign in terms of numbers of households and total mass of residual household waste analysed. In total, 1,474 households were included in this study, and the number of households investigated in each area varied between 100 and 200, as recommended by Nordtest (1995). Overall, a total of 12 tonnes of residual household waste was collected and manually sorted. To investigate the effect of periodic variations in food waste generation, residual household waste was sampled repeatedly from the same single-family house area in the municipality of

Gladsaxe in May 2011, October 2011 and March 2012.

The households involved in this sampling campaign were selected by the municipal authorities responsible for solid waste management, with the aim of ensuring that these homes were representative of the investigated area (Table SM 3). Before sampling began, the selected households were asked if they would like to participate in three waste sampling campaigns in the future, without indicating the exact dates. This was done by telephone and mail. First, the telephone interview was used to obtain the consent of households to participate to waste sampling campaign. After obtaining the consent, a confirmation letter was sent to households that accepted to participate to the waste sampling campaign. Based on this method, we obtained up to 80% of interviewed households that accepted to participate to the sampling campaign. This method was applied in order to comply with Danish waste regulations (Danish EPA, 2014) and also to avoid any potential changes in household behaviour, which could hamper the reliability of the results. Thus, one week or two weeks´ residual household waste was collected from those households enjoying weekly existing collection schedule. After sampling, the waste was transported using non-compacting tipping trucks to the sorting facility. The residual household waste was sorted within a week from the sampling day to minimise the degradation of food products

(Edjabou et al., 2015).

2.4 Food waste sorting

The residual household waste (Table 2) was sorted into six food waste fractions and other waste material fractions. The six food waste fractions were further sorted into detailed fractions, which in turn were grouped into 11 food categories (Table SM2).

Although the six food waste fractions were clearly defined and illustrated by examples, we encountered some difficulties that were overcome by sorting consistently these food products throughout the sorting campaign. A food product naturally composed of inseparable avoidable and unavoidable components was considered as avoidable food waste. For examples, a whole chicken, containing both meat (avoidable) and bones (unavoidable) was sorted as avoidable food waste. Similarly, whole fish, banana, etc. were sorted as avoidable food waste. We differentiated between processed and unprocessed food waste as follow: food waste is unprocessed when the whole food product was disposed with or not packaging, whereas discarded food products that were partly eaten or destroyed was sorted as processed food waste. Skin and peels of fruit and vegetables that were removed prior disposal were sorted as unavoidable food waste..

The waste sorting methods involved ‘batching’ sorting for waste from the multi-family house areas and individual waste bin sorting for waste from the single-family house areas.

2.4.1 Single-family house areas

In the single-family house areas, the residual waste was collected separately from each household. Initially, the bins were sealed tightly, to prevent losses and to separate them from other bins. Finally, the waste bins were labelled with the address of the household from where it was collected. The bins were sorted separately, and food waste data were obtained for each household. Information on the number of persons per household was provided by the municipal authorities.

The sorting of indiviudal household waste bins enables to investigate differences and distribution (Dahlén and Lagerkvist, 2008), but it is very costly and demands a great deal of effort. Additionally, it is only feasible in single-family house areas.

2.4.2 Multi-family house areas

It was neither economically nor technically feasible to collect and separately sort the waste from each household in these areas. Instead the waste was mixed and transported to the sorting facility, where it was sorted as a ‘batch’ (Edjabou et al., 2015). Here the waste from each area was treated as a “single sample.” As a result, we obtained one dataset from each of the multi-family house area.

Batch sorting is less labour intensive and suitable for all housing types. While it may avoid sampling and splitting errors (Edjabou et al., 2015), it does generate data that may not describe waste distribution between households.

2.5 Food waste data and statistical analyses

Given the waste sampling and sorting procedures, distributions of food waste per household were only available from the single-family house areas. However, data from multi-family house areas described differences between municipalities.

The average quantities and composition of food waste were calculated as weighted average according to the distribution of the Danish population as shown in Tables SM 4 & SM 5 (Statistics Denmark, 2015).

We applied permutation tests (Kabacoff, 2011) to compute p-values. A bootstrap, applied on a robust regression, was used to calculate a 95% confidence interval and estimates of measurement precision (Fox and Weisberg, 2012). A permutation test and bootstrap methods were applied, because they do not require distribution assumptions for the data, and they are less sensitive to outliers (Kabacoff, 2011).

We investigated whether or not the mass of food waste was influenced by housing type, by comparing the average data from each of the two areas. Furthermore, we analysed factors influencing the mass of food waste in the single-family house areas and compared the relationship between individual food waste fractions. The households' generation of food waste was analysed by means of a permutation test extended to logistic regression. Here, the binary variable was whether a household generated food waste (mass higher than zero) or not (the mass was zero) (Kabacoff, 2011).

The effect of the sample size was analysed for each food waste fraction by assessing the relationship between the confidence intervals and the sample size (number of households). The confidence intervals were computed using bootstrapping (Crawley, 2005). This method was chosen because traditional sampling plans assume specific classical probability distribution (typically normal distribution) of either the population or of the parameters of the population to be estimated. However, given the heterogeneity of waste fractions, a very large sample at unacceptable cost should be considered to ensure each fraction is distributed normally. Moreover, the composition studies showed that almost no waste fraction generation and composition is normally distributed (Klee, 1993). For these reasons, traditional sampling theories are not suitable to estimate the required sample size in order to determine the quantity or the composition of solid waste (Klee, 1993)assume specific classical probability distribution (typically normal distribution) of either the population or of the parameters of the population to be estimated. However, given the heterogeneity of waste fractions, a very large sample at unacceptable cost should be considered to ensure each fraction is distributed normally. Moreover, the composition studies showed that almost no waste fraction generation and composition is normally distributed (Klee, 1993). For these reasons, traditional sampling theories are not suitable to estimate the required sample size in order to determine the quantity or the composition of solid waste (Klee, 1993).

The data were modelled using the statistical and graphical software R (http://www.r-project.org).

3 Results and discussion

3.1 Analysis of sample size for each municipality

We simulated sample sizes (k: to determine) between 5 and 782, and for each sample size we used 10,000 replicates. The results show that the bootstrap 95% confidence intervals for food waste fractions narrowed sufficiently to suggest that a sample size of 100-200 households would produce reliable results. This simulation confirms the sample size recommended by Nordtest (1995).

3.2 Quantities and composition of food waste fractions

Tables 3 & 4 show respectively the weighted average of wet mass and the composition of food waste. Figure 1 illustrates the average mass of food waste generated in a Danish household, split into unavoidable and avoidable, which were further split into the six food waste fractions. The mass of vegetable (suitable for home composting) and animal-derived food waste are also provided.

The total weighted mass of residual waste generated in an average Danish household amounted to 434 ± 18 kg per year (Figure 1), or 201±13 kg per person per year. Thus, per mass, the largest contribution to residual household waste was from food waste (43±1.8%) as shown in Table 3. These results are consistent with previous Danish studies, which reported 42% (Edjabou et al., 2015) and 41% (Riber et al., 2009) food waste.

Food waste in Danish households consisted of 56.4±3.8% of avoidable food waste and 43.6±2.2% of unavoidable food waste (Table SM 6). The avoidable food waste amounted to 103±9 kg per household per year (Figure 1), or 48±4 kg per person per year. These results differ from those estimated by EUROSTAT at 7 kg per person per year (Monier et al., 2010) and 126 kg per household (Brautigam et al., 2014) as shown in Table 5. However, Monier et al. (2010) acknowledged their estimates may include high uncertainties, and so they recommended undertaking a waste stream analysis to estimate reliable data. The mass of avoidable food waste from Danish households was also lower than those found in the UK (210 kg per household per year (WRAP, 2011)), the United States (124 kg per person per year (Koester, 2013)) and in Canada (117 kg per person per year (Parizeau et al., 2014)). However, this figure is in the range of those reported in Austria (33 kg per person per year (Lebersorger and Schneider, 2011)) and Finland (23 kg per person per year (Koivupuro et al., 2012)). This discrepancy between countries confirms the difficulty of extrapolating avoidable food waste data.

Avoidable processed food waste, which occurs after cooking, serving or preparation (Section 2.1) accounted for 30% of all avoidable food waste (Table 3 and Table SM 6) and was 34±5kg per household per year (Figure 1), or 16±3 kg per person per year. Avoidable unprocessed food waste constituted 67% of all avoidable food waste (Table 3 and Table SM 6) and was estimated at 79±9 kg per household (Figure1) per year, or 32±4 kg per person per year. These results indicate that a high proportion of avoidable food waste was food that had been purchased, stored (or not) and then discarded.

On average, 71% of the avoidable food waste consisted of vegetable products, which amounted to 73±8 kg per household per year (Figure 1), or 35±2 kg per person per year. The corresponding 29% of avoidable animal-derived food waste indicates that Danish households discard a relatively small mass avoidable animal-derived food waste compared to avoidable vegetable food waste. Moreover, given that animal-derived food waste consisted of animal products and a mix of animal products and vegetable products, such as salads (Table 1), we could conclude that the mass of avoidable animal products may be smaller than the mass of avoidable animal-derived food waste.

While the mass of avoidable animal-derived food waste consisted of 50% unprocessed avoidable food waste, avoidable vegetable food waste comprised 74% of avoidable unprocessed food waste (54±6 kg per household per year) and 36% avoidable processed food waste (19±7 kg per household per year), as shown in Figure 1. This result indicates that about 74% of the avoidable vegetable food waste may be food that has been purchased and then thrown away, without having been cooked, prepared or served as a meal. These results could be explained mainly by inefficient purchase planning, causing unnecessary and excessive food that neither could be eaten nor preserved for a longer period(FUSIONS, 2014; Halloran et al., 2014; Parizeau et al., 2014; Silvennoinen et al., 2012).Thus, shopping planning reduce (Silvennoinen et al., 2014; Stefan et al., 2013; WRAP, 2009) and the correct storage of vegetables and fruits (WRAP, 2009) could reduce substantially the mass of avoidable food waste in the Danish households. Additionally, recipes for food leftovers and cooking planning (WRAP, 2009) should be considered to reduce food waste from household.

3.2 Composition of food categories

Food waste fractions were grouped in food categories (Table 1 and Table SM 2). Each food category was further subdivided into avoidable and unavoidable food waste as shown in Figure 2. Overall, the dominant food products were fresh vegetables and salads (30% of total food waste) and fresh fruit (17% of total food waste), followed by bakery (13% of total food waste), and drink and confectionery and desert (13% of total food waste).

The predominant avoidable food categories from Danish houses were fresh vegetables and salads (14% of total food waste) and bakery (13% of total food waste). However, fresh vegetables and salads (16% of total food waste), fresh fruit (12% of total food waste) and drink, confectionery and desert (11% of total food waste) were the dominant unavoidable foods. A relatively high percentage of drink, confectionery and desert in unavoidable food waste was mainly due to spent coffee grounds. These results are comparable to those found by WRAP (2009) for which fresh vegetables and salads, drink, fresh fruit, bakery and meal (home-made and pre-prepared) were dominant in the UK.

3.3 Occurrence of food waste

We analysed whether a single-family household generated one of the six food waste fractions or not. In this section, occurrence of food waste refers to whether household generated food waste fractions or not. This approach aimed to assess the availability of food waste fractions generated from the single-family house areas. Owing to the waste data for each household, we computed the number of households where “zero mass” of food waste were found in the waste bin. The analysis was done for each of the six food waste fractions.

The occurrence of food waste from the Danish households was analysed by assessing how many cases where “zero mass” of food were found in the waste bins. The analysis was done for each of the six food waste fractions. The percentage of households (single-family house areas) that did not generate food waste as function of household size is presented in Table 6. The results show that 97% of households involved in this study generated avoidable food waste, suggesting that this practice occurs in most of Danish households. Avoidable processed food waste was found in 68% of bins. Consequently, initiatives to reduce avoidable food waste could be carried out at national level, even though municipalities have the responsibility for the management and prevention of municipal solid waste (Danish EPA, 2014), as suggested by Halloran et al. (2014). Moreover, 98% of household generated unavoidable food waste. These figures suggest that, initiatives to reduce avoidable food waste should be accompanied by other initiatives that enable efficient resource recovery with minimum environmental impacts from food waste that cannot be avoided.

Logistic regression was applied to assess the factors influencing food waste generation (Table SM 7). The binary variable was food waste generation (yes/no), where “yes” meant that food waste fraction was found in the bins, and where “no” meant that it was not found. The explanatory variables were regions, municipalities and household size (Table SM 7).

The results show that only the variable household size might affect significantly households´ food waste generation (Table 6). This suggests the likelihood that food waste is generated will increase significantly according to the number of occupants in the household. As a result, a house containing two persons may increase this likelihood of generating food waste by a factor of four, and a house containing more than two persons may increase this figure by a factor of five or more.

Waste sampled from three different periods from the same households showed that 94-97% generated avoidable food waste, whereas 97-98% generated unavoidable food waste (Figure SM 1). The statistical analysis showed that periodic variations did not significantly affect household food waste generation in this respect. The size of household significantly influenced the generation of food waste from the Danish households (Tables SM 8 & SM 9).

These results suggest that an increase in the number of persons per household increases the likelihood of wasting food. A possible explanation for this might be that a person living alone (household containing one person) tends to eat "simplified" or "cold meal" consisting of bread (e.g. rye bread) with cold or fried fish, cold meats, warm meats, etc…, soup, and ready meals. They may also eat at work. As a result, these households may merely generate food waste (Table 6), although they may generate other waste materials such as packaging. However, a house containing more one person may keep "classical" or "traditional" meal habit, especially for dinner where warm meal or prepared food is served. The process of preparing, cooking and serving food at home for more than one person may increase the risk of overestimation during purchasing and cooking, leading to food waste generation. This uncertainty may increase when the size of household increases because it is apparently more difficult to plan efficiently purchasing and cooking of food that satisfy the desire of all the household members. These results suggest that in the single-family house areas, households with one person could affect the availability of food waste for home composting and biogas plants. These plants rely on a continuous availability of organic material

3.4 Factors influencing the quantity of individual food waste fraction

First we analysed the significance differences in the quantity of food waste between single-family and multi-family areas. Second, we investigated that may influence the quantity of food waste from the single-family house areas.

3.4.1 Influence of housing type on food waste

The mass of residual household waste per household was significantly higher in single-family house areas (8.7±0.2 kg per household per week) than in multi-family house areas (7.8±0.1 kg per household per week) (Table 4). However, this difference was not significant when considering the mass per person. Similarly, single-family house areas generated significantly higher mass of food waste, avoidable food waste and unavoidable food waste per household than multi-family house areas (Table 4). In contrast, considering the mass per person, the mass of total food waste, avoidable and unavoidable food waste was similar between single-family house areas and multi-family house areas. Regardless of factors such as socio-economic differences, these results may suggest that the results of statistical analysis applied to the mass of food waste, depends on the unit generation rates of food waste (mass of food waste per household or mass of food waste per person). This could be explained by the difference in the number of occupants per household, which is 2.4 for single-family house areas and 1.8 for multi-family house areas (Statistics Denmark, 2015).

In the following sections (3.4.2 to 3.4.5), we investigated the influence on the quantity of food waste from single-family house areas, based on (1) household size, (2) municipality, (3) region and (4) the difference between municipalities offering a free composter for home composting and those, which do not provide such a service. For the latter factor, we did not assess differences in the numbers of households engaged in home composting; we considered the mass of food waste per household and per person.

3.4.2 Geographical variation

Geographical variations include the influence of regions and municipalities on the generated mass of food waste. The distribution between households of the mass of avoidable and unavoidable food waste as a function of household size in single-family house areas is shown in Figures 3A & 3B for mass per household and Figures 3C & 3D for mass per person. The results show that geographical variations including municipalities (df=3, $p>0.05$) and regions (df=1, $p>0.05$) did not make any significant difference to the mass of avoidable and unavoidable food waste per household and per person. Similarly, we found no significant difference in the mass of the six detailed food waste fractions, respectively, between municipalities and regions in Denmark. These findings indicate that the generation of avoidable food waste, as well the detailed food waste fractions, were not affected by geographical differences such as municipalities or regions.

3.4.3 Household size

We analysed household size as a categorical explanatory variable. The result showed that the mass of food waste (see Table 1 and Table SM 1) per household may increase significantly in line with the size of household. For the mass of avoidable food waste per household, households containing one person generated significantly lower avoidable food waste than those containing two persons (0.66 kg, with a 95% confidence interval of 0.23 to 1.44), three persons, (1.85 kg, with a 95% confidence interval of 1.36 to 2.34) and four or more persons (2.75 kg, with a 95% confidence interval of 2.30 to 3.12), as shown in Table 7. These findings are consistent with those of Parizeau et al. (2014), Silvennoinen et al. (2014) and WRAP (2009). Similarly, the mass of unavoidable food waste was also significantly affected by household size (Table 7).

The mass of food waste decreased when household size increased, except for avoidable processed food waste (avoidable processed animal-derived food waste, avoidable processed vegetable food waste and total avoidable processed food waste)

(Tables SM 10 & SM 11). For example, households containing one person generated higher avoidable food waste than those containing two persons, three persons and more than three persons as it shown in Table 7. However, this difference was not statistically significant, thereby suggesting that there was no significant difference in the mass of avoidable food waste per persons among households. Although these results differ from those published by Parizeau et al. (2014), who found a negative correlation, they are nevertheless consistent with those of WRAP (2009), Katajajuuri et al.(2014), Koivupuro et al. (2012) and Silvennoinen et al. (2014). In contrast, the mass of unavoidable food waste per person decreased significantly in line with the number of persons per household. Thus, a household containing three or more may generate, respectively, 18 kg (a 95% confidence interval of 8 to 28) per person per year and 22 kg (a 95% confidence interval from 14 to 32) per person per year, which is significantly lower than for one person (Table 8). This discrepancy could reflect the difference in the generation of avoidable and unavoidable food waste from the Danish households.

The comparison between the mass of avoidable and unavoidable food waste per household showed that on average, Danish households generated 24 kg (95% confidence interval from 15 to 33) per household per year significantly higher avoidable food waste than unavoidable food waste. The results according to household size showed that households containing three or more persons generated 33 kg (95% confidence interval 16 to 52) per household per year significantly higher avoidable food waste than unavoidable food waste. However, households containing one and two persons generated comparable mass of avoidable and unavoidable food waste. Figures 4 present the bootstrap 95% confidence interval and mean of unprocessed vs. processed and vegetable vs. animal-derived per household (Figures 4A & 4B) and per person (Figures 4C & 4D). The results also showed that the difference in the mass of food waste generated per household, between (1) avoidable unprocessed food waste and avoidable processed food waste and (2) vegetable and total animal-derived food waste, increased significantly in line with household size.

A possible explanation for these results may be that households with one person may only cook food to satisfy their own desire, at least less often than those with more than one person. Furthermore, easy accessibility to shops enables householders to make smaller purchases (Gjerris and Gaiani, 2013). Thus, households containing one person could purchase food products that they want for themselves, even though promotions and price discounts could affect the type and mass of what they buy (Jahns et al., 2014).

3.4.4 Free composter for home composting

We analysed the influence of the ‘free composter’ on the mass of food waste discarded in single-family house areas by comparing those municipalities offering free composter and those that do not.

The result of the permutation test showed that offering a free composter did not make a significant difference to the mass of food discarded by single-family households. Surprisingly, the mass of vegetable food waste was not significantly influenced either. These results may suggest that municipalities where free composters are offered generated a comparable mass of food waste compared to those that do not offer such a service. Since we did not determine the number of households engaging in home composting as a result of being given a free composter, these results should be interpreted with caution.

The results showed that about 145±9 kg per household per year could be home-composted (Figure 1) in Danish households and as a result reduce 33±2% of the total residual household waste. However, the current incentive via free of charge composters has not made any significant differences in this respect, especially for vegetable food waste. Tucker and Speirs (2003) argued that negative perceptions, such as vermin, flies, space, aesthetics, etc., may determine households’ reticence to take composting on board. They also found that factors such as time and effort could influence the issue. Therefore, Tucker and

Speirs (2003) suggested awareness programmes focusing on changing perceptions, such as “composting does not necessarily attract flies and vermin” and “composters can be beautiful.” Refsgaard and Magnussen (2009) proposed including institutional and organisational solutions in addition to technical solutions such as providing composters and financial incentives to motivate households. An alternative could be a central composting or combined anaerobic and aerobic treatment plant.

3.4.5 Periodic mass of household food waste

The mass of food waste generated from households during the three periods, and the p-values of the permutation test (Kabacoff, 2011), are presented in Table 8.

Overall the results showed that the mass of food waste generated in Danish households was not significantly different between the three periods. However, only the mass of unavoidable animal-derived food waste per household and per person (4 to 6% of total food waste) was significantly different through this time span. These results could be explained by the demand for fresh food through the whole year and the modern food chain that enables retailers to import out of season produce (HLPE, 2014). However, in contrast to these results, another study found significant monthly variations in Canada, which were explained by the increased supply of fresh food in the summer months at more affordable prices (Adhikari et al., 2008).

Figures 5 show the distribution of food waste as a function of household size, grouped per period per household (Figures 5A & 5B) and per person (Figures 5C & 5D). Concurrently, the mass of avoidable and unavoidable food waste per household increased in line with the size of the household. Compared to a household containing one person, the mass of avoidable food waste may increase by 1.15 kg (with a 95% confidence interval of 0.76 to1.53) per week for a household containing two persons, 1.72 kg (with a 95% confidence interval of 0.40 to 2.97) per week for household containing three persons and 2.42 kg (with a 95% confidence interval of 1.52 to 3.31) per week for more than three persons. However, the mass of avoidable food waste per person also increased in line with household size, albeit not significantly.

The mass of unavoidable food waste per household increased significantly in line with the number of occupants per household, whereas the mass per person decreased insignificantly in relation to household size (Figures 5A & 5B). These results are consistent with those found for the four municipalities (Section 3.4.2).

3.4.6 Influence of household with “zero mass” of food waste

The influence of household that did not generate food waste during this sampling period on the outcome of statistical analyses was investigated by comparing two datasets: (1) all households (in single-family house areas) included in the sampling campaign and (2) those that actually generated food waste. This means that households that did not generate anything were excluded in the second datasets for each food waste fraction.

We found a significant difference between datasets for the following: avoidable processed food waste avoidable processed vegetable food waste, avoidable processed animal-derived food waste, avoidable unprocessed animal-derived food waste, and unavoidable animal-derived food waste (Table SM 12). For these waste fractions, the mass per person increased in line with the size of household.. However, if we consider only the dataset for households that generated food waste, we found that the mass of food waste per person decreased when the household size increased – as expected.

5 Conclusions and future prospects

In the present study, we provided data for the occurrence, the mass and the composition of food waste from Danish households based on waste stream analysis.

The results showed that most of the Danish households generated avoidable (97% of households) and unavoidable (98% of households) food waste independently of regions, municipalities and sampling period. Moreover, the occurrence of food waste generated by households was driven by household size. The results indicate a Danish household containing one person is less likely to generate avoidable food waste compared to other household sizes.

We found that avoidable food waste was the predominant food waste fraction, suggesting that a reduction of avoidable food waste could reduce considerably the total mass of Danish residual household waste. However, an efficient treatment of unavoidable food waste could ensure resource recovery.

Although, the results showed that the mass per household of food waste fractions increased in line with household size, the statistical analysis revealed that there was no significant difference among household sizes of the aggregated mass per person for individual fractions, avoidable and unavoidable food waste.

A combining waste stream analysis based on food categories, households purchasing data, and their consumption patterns-type should be considered to determine the mass of food purchased and the mass of food consumed. These data could provide better insight of the detailed food products that are wasted from households. This information enables to develop efficient and local based solution to reduce food waste from households.

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Supplementary material (SM)

Supplementary materials contain detailed food waste data used for calculations and figures. SMs are divided into tables (Table SM) and figures (Figure SM).

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Tables

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Food waste generation and composition from Danish households

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Table 1: Food categories and food products included in the six food waste fractions-Last column shows example of food products that is not included

Food waste fractions	Food categories[a]	Included food products	Excluded food products
Avoidable unprocessed vegetable food waste (AUVFW)	Bakery	Bread, cakes (packed or not)	Bread used for sandwiches.
	Drinks and confectionery and desserts	Tea bags, coffee grounds, biscuits, chips, beer, alcohol, etc.	
	Condiments, sauces, herbs and spices	Ketchup, peanut butter, sauces, salt, honey, jam, olives, mayonnaise, salt, sugar, etc.	
	Fresh fruit	Banana, apple, melon, other fruits, etc.	Fruits prepared or served at home -half eaten.
	Fresh vegetables and salads	Carrots, potatoes, other fresh vegetables, etc.	Home cooked or served vegetables, salad.
	Stable food	Breakfast cereal, rice, pasta, flour, etc.	Cooked rice, pasta, etc.
	Canned food	Corn, bean, pineapple, other tinned vegetables	
	Other food	Other uncooked vegetable food.	
Avoidable processed vegetable food waste (APVFW)	Bakery	Vegetable pizza, pizza bread, etc.	Bread used for sandwiches, meat pizza.
	Stable food	Rice, pasta, etc. (cooked or served at home).	
	Fresh vegetables and salads	Potatoes, yams, vegetables, etc. (cooked or served at home).	
	Other food	Other cooked, prepared or served food at home.	
Unavoidable vegetable food waste (UVFW)	Drinks and confectionery and desserts	Spent coffee grounds, tea bags, etc.	Unused tea bag, coffee grounds
	Fresh fruit	Skin (e.g. pineapple), peals (e.g. banana), stones (e.g. avocado), (fruits rinds (e.g. melon).	Half eaten fruit, rotten fruit, etc.
	Fresh vegetables and salads	Skin (e.g. potatoes, carrots, onion), peels (e.g. courgette, cucumber, etc.), etc.	Half eaten vegetables.
	Canned food	Brine from canned vegetables food , etc.	
	Pet food	Vegetable pet food.	
	Other food	Other inedible vegetables and fruits.	
Avoidable unprocessed animal derived food waste (AUAFW)	Dairy and eggs	Eggs, dairy products (milk, yoghurt, cheese, margarine, butter, etc.).	Cooked eggs, opened and served dairy products.
	Meat and fish	Meat, fish, packed cold meat, cut meat.	Opened meat package -cooked or served.
	Canned food	Canned meat and fish, canned mixed animal and vegetable products, etc.	Opened canned vegetable.
	Other food	Other mixed of vegetable and animal products.	Opened canned mixed or only animal products.
Avoidable processed animal derived food waste (APAFW)	Bakery	Bread found in sandwich prepared and served at home.	
	Dairy and eggs	Cooked or fried eggs, cheese served at home, etc. and edible leftover.	
	Canned food	Opened canned meat and fish food.	Unopened canned vegetable food.
	Meat and fish	Cooked, prepared or served at home (meat, fish, etc.).	
	Other food	Other mixed of vegetable and animal products cooked, prepared or served at home.	Unopened canned mixed or only animal products.
Unavoidable animal derived food waste (UAFW)	Dairy and eggs	Cheese rinds, eggs shells, etc.	Half or leftover eggs and dairy products.
	Meat and fish	Meat and fish (skin, rinds, fat, etc.), fish heads, shellfish shells, etc.	
	Pet food	Animal or mixed animal and vegetable pet food.	
	Other food	Other non-edible mixed of animal and vegetable products.	

[a]*Grouped food categories were adapted from WRAP (2009) and Lebersorger and Schneider (2011) See Table SM 1 for food categories.*

Table 2: Number of household per area and the total amount of residual household waste generated during one week

Housing types	Municipalities	Regions	Number of households per sampling unit	Amount analysed (kg wet mass)[1]
Single-family	Gladsaxe	Zealand	111	1,100
	Gladsaxe	Zealand	98	1,100
	Helsingør	Zealand	189	2,000
	Kolding	Jutland	101	1,000
	Kolding	Jutland	93	1,000
	Viborg	Jutland	108	1,100
	Viborg	Jutland	82	1,000
Multi-family	Gladsaxe	Zealand	319	2,100
	Odense	Jutland	372	1,800
Total	-	-	1,474	12,200

[1]*Arounded amount of residual household analysed*

Table 3: Composition of food waste (in mass per wet basis: w/w)

	SFHA[a] (n=7)[c]		MFHA[b] (n=3)[c]		Denmark (Weighted average)[d]	
	Mean	SD[e]	Mean	SD[e]	Mean	SD[e]
Composition						
Avoidable food waste						
Avoidable processed food waste						
Avoidable processed animal-derived food waste (% w/w)	7.8	1.1	8.9	3.04	8.2	1.3
Avoidable processed vegetable food waste (% w/w)	8.9	0.9	13.0	4.8	10.5	1.8
Avoidable unprocessed food waste						
Avoidable unprocessed animal-derived food waste (% w/w)	8.3	0.8	7.3	2.3	8.0	1.0
Avoidable unprocessed vegetable food waste (% w/w)	30.6	1.2	28.5	7.7	29.8	2.9
Unavoidable food waste						
Unavoidable animal-derived food waste (% w/w)	3.9	0.8	5.2	1.1	4.4	0.6
Unavoidable vegetable food waste (% w/w)	40.6	1.9	37.0	4.7	39.2	2.1
Total	100		100		100	
Food waste (% w/w of total residual household waste)	41.0	0.8	43	4.7	43	1.8

[a] *Single-family house areas*
[b] *Multi-family house areas*
[c] *Number of sampling areas (see Table 1)*
[d] *Weighted average was calculated with 60% single-family houses and 40% multi-family houses (Statistics Denmark, 2015).*
[e] *Standard deviation.*

Table 4: Generation rate of food waste (in mass per wet basis: w/w)

	SFHA[a] (n=7)[c]		MFHA[b] (n=3)[c]		Denmark (Weighted average)[d]	
	Mean	SD[e]	Mean	SD[e]	Mean	SD[e]
Food waste (kg/household/week)	3.50	0.1	3.8	0.2	3.5	0.1
Food waste (kg/person/week)	1.47	0.04	1.97	0.1	1.6	0.0
Residual household waste (kg/household/week)	8.71	0.2	7.81	0.9	8.4	0.3
Residual household waste (kg /person/week)	3.55	0.2	4.6	0.2	3.9	0.1

[a] *Single-family house areas*
[b] *Multi-family house areas*
[c] *Number of sampling areas (see Table 1)*
[d] *Weighted average was calculated with 60% single-family houses and 40% multi-family houses (Statistics Denmark, 2015).*
[e] *Standard deviation.*

Table 5: Review of household avoidable food waste (wet mass basis)

Countries	Avoidable food waste (wet kg per year)		Methods	Source
	Household	Capita		
Denmark[a]	48	103	WSA[a]	
UK	210	88	WSA[a], diary and statistics	(WRAP, 2009)
Austria	-	33	WSA[a]	(Lebersorger and Schneider, 2011)
Sweden	60		WSA[a]	(Bernstad Sariva Schott et al., 2013)
EU	-	115	Database	(Brautigam et al., 2014)
DK	-	126	Database	(Brautigam et al., 2014)
Germany	-	7	Questionnaire	(Jörissen et al., 2015)
Italy	-	7	Questionnaire	(Jörissen et al., 2015)
Germany	-	78	Modelling	(Jörissen et al., 2015)
Italy	-	42-104	Modelling	(Jörissen et al., 2015)
US	-	124	Literature review	(Koester, 2013)
UK	-	73	Diary	(Langley et al., 2010)
EU	-	47	Database	(Monier et al., 2010)
Denmark	-	7	Database	(Monier et al., 2010)
Finland	-	23	Diary	(Silvennoinen et al., 2014)
Canada	-	218	WSA[a]	(Parizeau et al., 2014)

[a] *Current study*

[b] *Waste stream analysis*

Table 6: Percentage of households that did not generate food waste (“no”) as function of household size (% n/n)[a] in the single-family house area

Household size	1 person	2 persons	3 persons	4+ persons	Total
Number of households	95	304	113	270	782
Avoidable food waste (% n/n)	11	3	0	13	3
Avoidable processed food waste (% n/n)	52	21	8	15	17
Avoidable processed animal-derived food waste (% n/n)	67	41	23	11	32
Avoidable processed vegetable food waste (% n/n)	60	36	25	1	30
Avoidable unprocessed food waste (% n/n)	15	5	2	14	4
Avoidable unprocessed animal-derived food waste	49	28	19	1	25
Avoidable unprocessed vegetable food waste (% n/n)	23	10	2	1	7
Unavoidable food waste (% n/n)	5	2	0	1	2
Unavoidable animal-derived food waste (% n/n)	28	14	12	6	15
Unavoidable vegetable food waste (% n/n)	8	3	1	1	3

[a] *Number of households that did not generate food waste (n) divided by number of total households for each household size (n)*

Table 7: Bootstrap estimates of standard errors and confidence intervals of the difference in amount of food waste (avoidable and unavoidable) as function of household size in single-family house areas

Household size	Coefficients		Standard Errors[c]		Bootstrap Confidence[a] Interval (95%-level) per household		Bootstrap Confidence[a] Interval (95%-level) per person	
	Household	Person	Household	Person	Lower	Upper	Lower	Upper
Avoidable food waste								
1 person	1.03	1.03	0.15	0.16	0.81	1.51	0.81	1.45
2 persons	0.66[b]	-0.19 [b]	0.18	0.16	0.22	0.96	-0.62	0.05
3 persons	1.85 [b]	-0.07 [b]	0.25	0.17	1.36	2.34	-0.50	0.18
4+ persons	2.75 [b]	-0.15 [b]	0.21	0.16	2.30	3.12	-0.60	0.08
Unavoidable food waste								
1 person	0.96	0.96	0.15	0.08	0.96	1.14	0.81	1.14
2 persons	0.85[b]	-0.05[b]	0.18	0.10	0.85	1.14	-0.25	0.14
3 persons	0.91[b]	-0.34[b]	0.25	0.10	0.91	1.24	-0.53	-0.16
4+ persons	1.34[b]	-0.43[b]	0.21	0.09	1.35	1.58	-0.62	-0.27

[a] Confidence interval that excluded zero, and indicating significant difference.

[b] Difference between household containing one person and other household size; (-) is lower than household containing one person and (+) means higher than household containing one person. Confidence interval containing zero means that the difference is insignificant, whereas confidence interval excluding zero means the difference is significant.

[c] Bootstrap estimate of standard deviation.

Table 8: Generation of food waste and total residual household waste in single-family house area of Gladsaxe as function of period and associated probability values from permutation test (kg wet-waste per week)

Material fractions	Period 1 (n=115)[a]		Period 2 (n=124)[a]		Period 3 (n=124)[a]		P-value[d]	
	HH[b]	PP[c]	HH[b]	PP[c]	HH[b]	PP[c]	HH[b]	PP[c]
Avoidable food waste	**2.22±2.13**	**0.87±0.81**	**2.6±2.49**	**1.01±1.34**	**2.25±2.18**	**0.84±0.8**	**0.55**	**0.37**
Avoidable processed food waste	0.66±0.85	0.24±0.29	0.70±0.96	0.24±0.29	0.85±1.03	0.31±0.39	0.12	0.18
Avoidable processed animal-derived food waste[g]	*0.32±0.51*	*0.12±0.2*	*0.33±0.43*	*0.11±0.13*	*0.38±0.54*	*0.13±0.2*	*0.34*	*0.67*
Avoidable processed vegetable food waste[g]	*0.34±0.52*	*0.12±0.17*	*0.37±0.74*	*0.13±0.24*	*0.47±0.65*	*0.18±0.26*	*0.22*	*0.13*
Avoidable unprocessed food waste	1.56±1.6	0.63±0.68	1.90±2.01	0.77±1.27	1.4±1.49	0.53±0.58	0.07	0.09
Avoidable unprocessed animal-derived food waste[g]	*0.3±0.38*	*0.13±0.21*	*0.38±0.45*	*0.15±0.18*	*0.26±0.57*	*0.10±0.26*	*0.18*	*0.27*
Avoidable unprocessed vegetable food waste[g]	*1.26±1.41*	*0.50±0.56*	*1.52±1.81*	*0.62±1.24*	*1.14±1.27*	*0.43±0.49*	*0.14*	*0.16*
Unavoidable food waste	**2.06±1.58**	**0.88±0.69**	**1.90±1.43**	**0.77±0.53**	**1.74±1.62**	**0.68±0.64**	**0.35**	**0.04**
Unavoidable animal-derived food waste[g]	*0.20±0.28*	*0.08±0.12*	*0.22±0.29*	*0.08±0.09*	*0.13±0.22*	*0.05±0.09*	*0.04*[f]*	*0.04*[f]*
Unavoidable vegetable food waste[g]	*1.87±1.46*	*0.80±0.64*	*1.68±1.34*	*0.69±0.51*	*1.60±1.5*	*0.62±0.58*	*0.17*	*0.19*
Food waste	**4.28±3.05**	**1.75±1.19**	**4.49±3.38**	**1.78±1.54**	**3.99±3.43**	**1.51±1.27**	**0.46**	**0.39**
Residual household waste	**8.86±4.64**	**3.76±2.13**	**9.38±5.2**	**3.84±2.3**	**8.62±5.64**	**3.47±2.53**	**0.62**	**0.84**

[a] Number of households in the single family house areas

[b] mean and standard deviation in kg wet waste per household per week

[c] mean and standard deviation in kg wet waste per person per week. Standard deviation describes the variation between single-family houses

d: p-values for the permutation test based on the amount of FW per households (HH) and per person (PP).

[f]: significance level $p<0.05$

[g]Detailed six food waste fractions

Figures

Figure 1: Weighted generation rate of food waste in Danish households in kg wet mass per household per year.

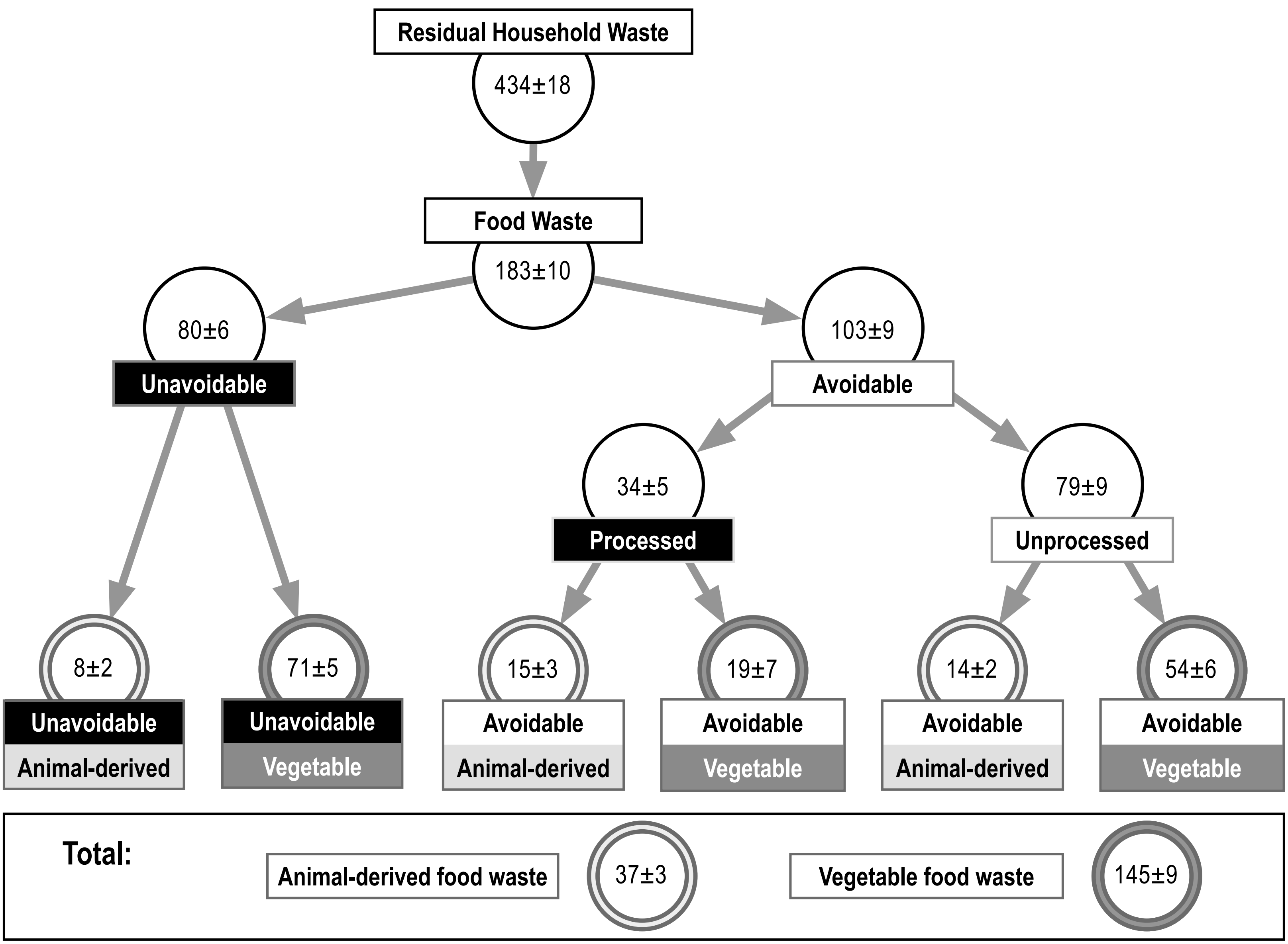
Figure 2: Weighted average composition of Danish household food waste (% mass per wet basis) based on food categories.

Figure 3: Distribution of the generation of avoidable and unavoidable food waste (box plots are based on wet mass basis) in the single family house areas as function of household size for the four municipalities: kg waste per household (A & B) and waste kg per person per week (C&D).

Figure 4: Comparison of the generation rates for different food waste fractions generated in single-family house areas between (wet mass basis of mean and 95% confidence interval are displayed): 1) unprocessed versus processed food waste fractions (A & C); 2) vegetable and animal-derived food waste fractions (B & D). The data are expressed in kg per household per week (A & B) and kg per person per week (C&D).

Figure 5: Periodic generation of avoidable and unavoidable food waste (box plots are based on wet mass basis) in the single-family house areas of Gladsaxe as function of household size: kg per household (A & B) and kg per person(C & D).

Figure 1



Residual Household Waste
434±18
Food Waste
183±10
80±6
Unavoidable
103±9
Avoidable
34±5
Processed
79±9
Unprocessed
8±2
Unavoidable
Animal-derived
71±5
Unavoidable
Vegetable
15±3
Avoidable
Animal-derived
19±7
Avoidable
Vegetable
14±2
Avoidable
Animal-derived
54±6
Avoidable
Vegetable
Total:
Animal-derived food waste
37±3
Vegetable food waste
145±9

Figure 2

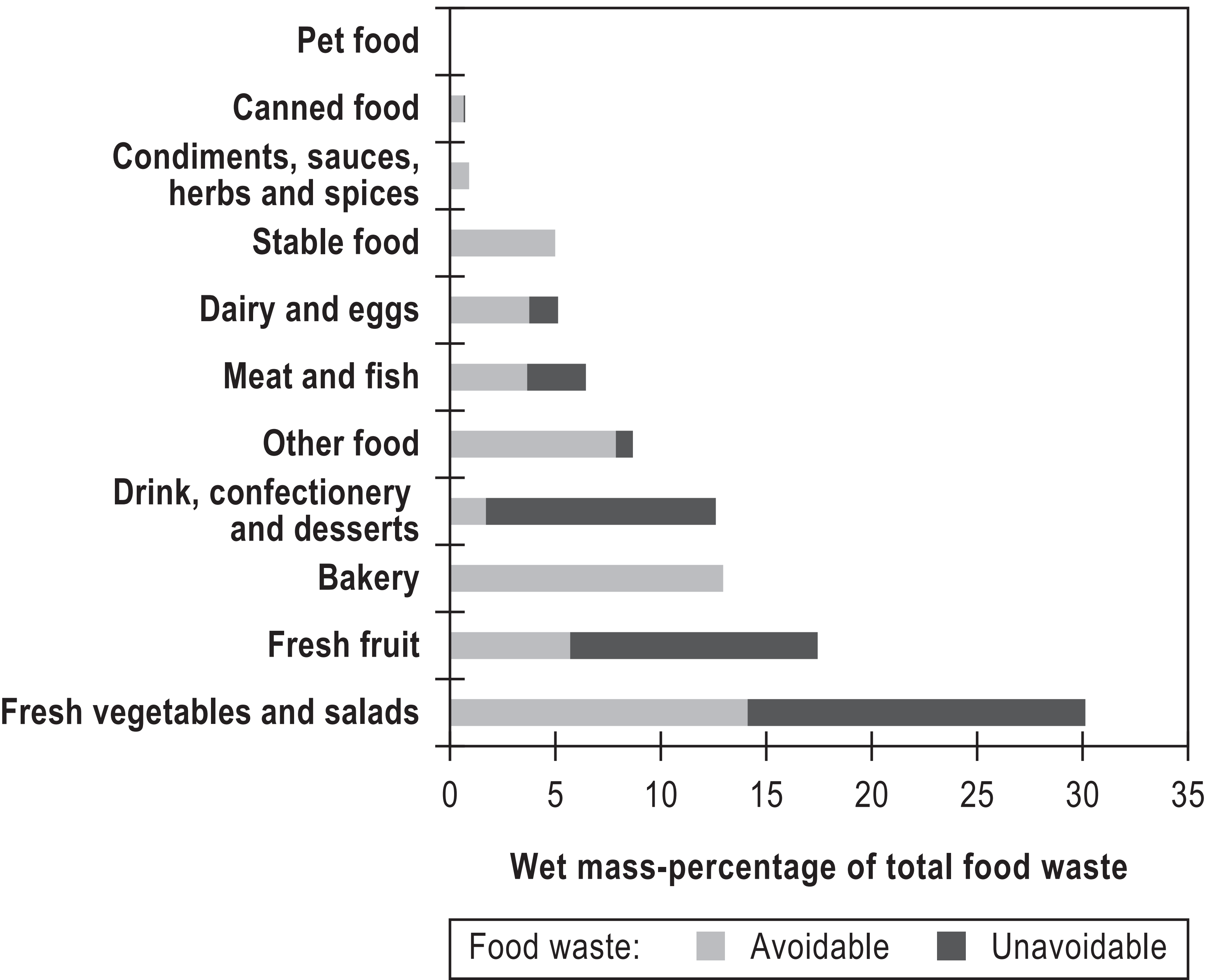
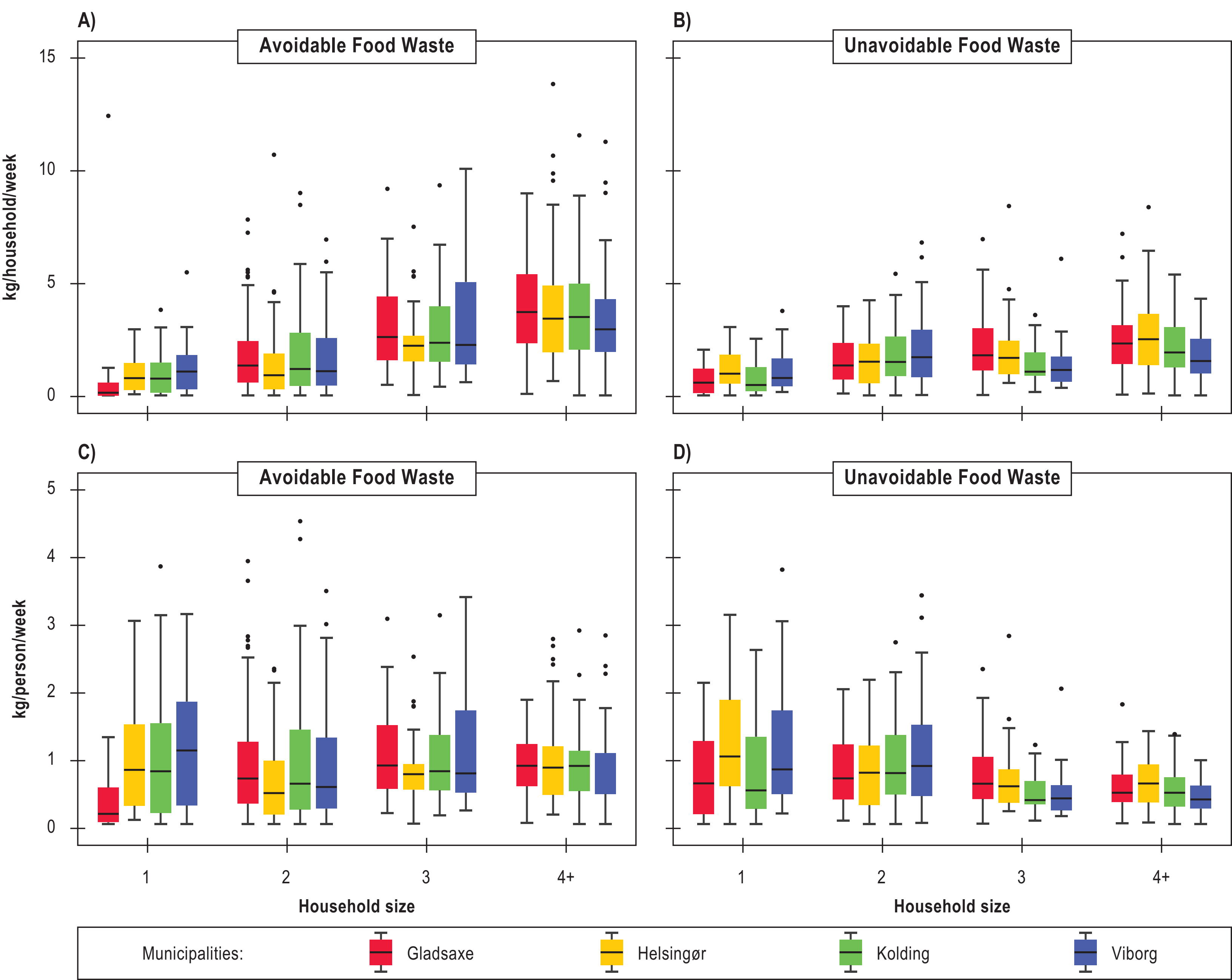
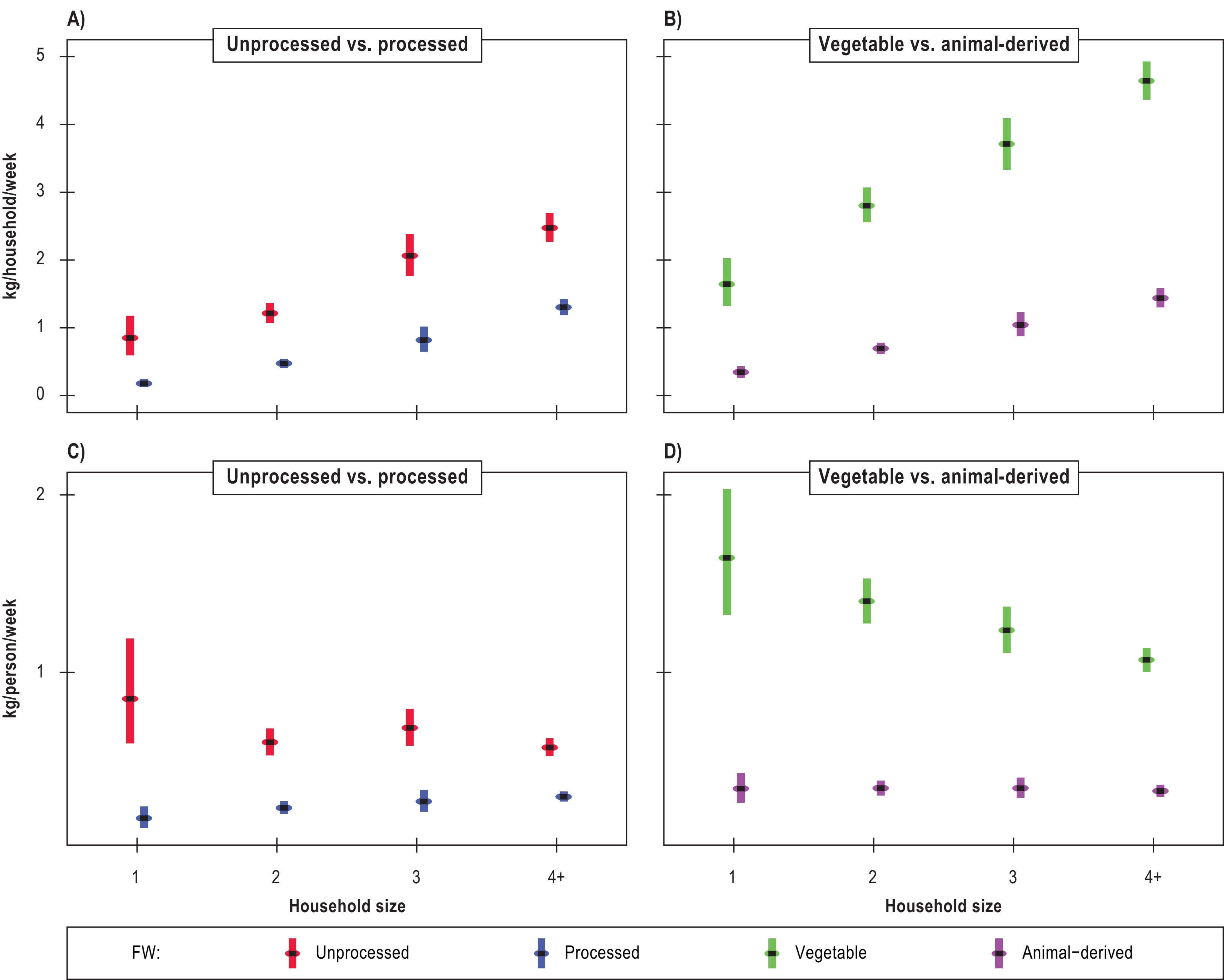

Pet food
Canned food
Condiments, sauces, herbs and spices
Stable food
Dairy and eggs
Meat and fish
Other food
Drink, confectionery and desserts
Bakery
Fresh fruit
Fresh vegetables and salads
0
5
10
15
20
25
30
35
Wet mass-percentage of total food waste
Food waste:
Avoidable
Unavoidable

Figure 3



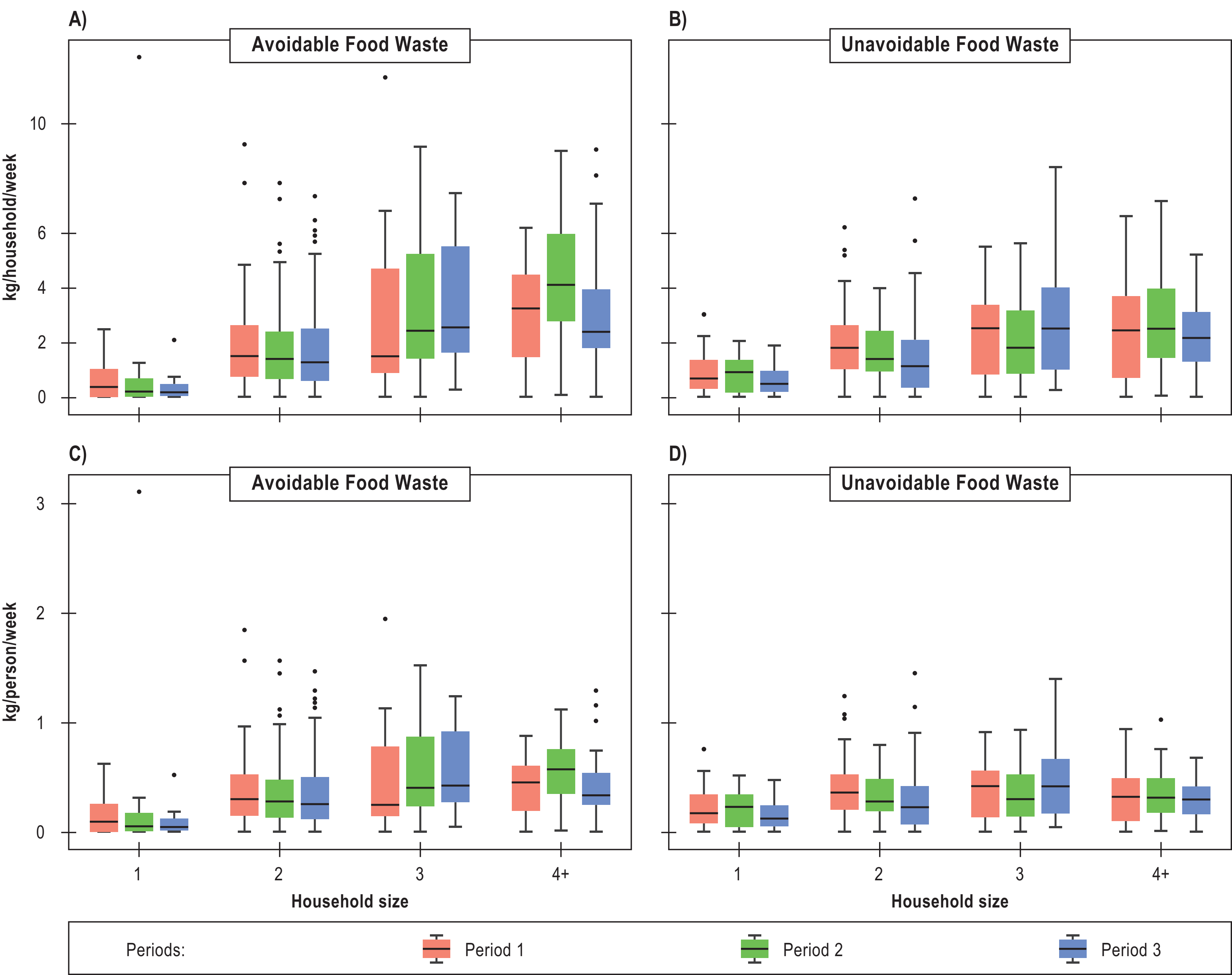
A)
Avoidable Food Waste
B)
Unavoidable Food Waste
C)
Avoidable Food Waste
D)
Unavoidable Food Waste
kg/household/week
kg/person/week
0
5
10
15
0
1
2
3
4
5
1
2
3
4+
Household size
Municipalities:
Gladsaxe
Helsingør
Kolding
Viborg

Figure 4



A)
Unprocessed vs. processed
B)
Vegetable vs. animal-derived
kg/household/week
5
4
3
2
1
0
C)
Unprocessed vs. processed
D)
Vegetable vs. animal-derived
kg/person/week
2
1
1
2
3
4+
Household size
1
2
3
4+
Household size
FW:
Unprocessed
Processed
Vegetable
Animal−derived

Figure 5



A)
Avoidable Food Waste
B)
Unavoidable Food Waste
kg/household/week
0
2
4
6
10
C)
Avoidable Food Waste
D)
Unavoidable Food Waste
kg/person/week
0
1
2
3
1
2
3
4+
Household size
Periods:
Period 1
Period 2
Period 3

Supplementary materials for the paper:

Food waste generation and composition fom Danish households

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Supplementary materials (SM)

Supplementary materials contain detailed food waste data used for calculations. SMs are divided into tables (Table SM) and figures (Figure SM).

Supplementary materials (SM) –Tables

Table SM1: Grouping of food waste fractions

Food waste sub-fractions	APAFW[a]	AUAFW[b]	UAFW[c]	APVFW[d]	AUVFW[e]	UVFW[f]
Avoidable food waste	X	X		X	X	
Unavoidable food waste			X			X
Animal derived food waste	X	X	X			
Vegetable food waste				X	X	X
Avoidable processed food waste	X			X		
Avoidable unprocessed food waste		X			X	
Food waste	X	X	X	X	X	X

[a] *Avoidable processed animal derived food waste.*
[b] *Avoidable unprocessed animal derived food waste.*
[c] *Unavoidable processed animal derived food waste.*
[e] *Avoidable processed vegetable food waste.*
[f] *Avoidable unprocessed vegetable food waste.*

Table SM 2: Food waste categories and fractions included

Grouped food categories	What it includes
Bakery	Bread found in sandwich prepared and served at home
	Bread, cakes (packed or not)
	Vegetable pizza, pizza bread, etc.
Canned food	Brine from canned vegetables food , etc.
	Canned meat and fish,
	Canned mixed animal and vegetable products, etc.
	Corn, bean, pineapple, other tinned vegetables
	Opened canned meat and fish food
Condiments, sauces, herbs and spices	Honey, jam, olives, etc.
	Mayonnaise, Ketchup,
	Peanut butter, sauces, salt, sugar
Dairy and eggs	Cheese rinds, eggs shells, etc.,
	Cooked or fried eggs, cheese served at home, etc. and edible leftover,
	Dairy products (milk, yoghurt, cheese, margarine, butter, etc.)
	Eggs,
Drinks and confectionery and desserts	Biscuits, chips, beer, alcohol, etc
	Spent coffee grounds, tea bags, etc.
	Tea bags, coffee grounds
Fresh fruit	Banana, apple, melon, other fruits, etc.
	Skin (e.g. pineapple), peals (e.g. banana),
	Stones (e.g. avocado), (fruits rinds (e.g. melon)
Fresh vegetables and salads	Carrots, potatoes, other fresh vegetables, etc.
	Peels (e.g. courgette, cucumber, etc.), etc.
	potatoes, yams, vegetables, etc. (cooked or served at home)
	Skin (e.g. potatoes, carrots, onion)
Meat and fish	Cooked, prepared or served at home (meat, fish, etc.)
	Fish heads, shellfish shells, etc.
	Meat and fish (skin, rinds, fat, etc.),
	Meat, fish, packed cold meat, cut meat,
Other food	Other cooked, prepared or served food at home,
	Other inedible vegetables and fruits
	Other mixed of vegetable and animal products
	Other mixed of vegetable and animal products cooked, prepared or served at home
	Other uncooked vegetable food
Pet food	Animal or mixed animal and vegetable pet food
	Vegetable pet food
Stable food	Breakfast cereal, rice, pasta, flour, etc.
	Rice, pasta, etc. (cooked or served at home)

Table SM 3: Distribution of household size of both households sampled and population for the four municipalities

Municipalities	Type of population	Household size (in %)				Total
		1	2	3	4+	
Gladsaxe	Sample	12	36	16	35	100
	Population	22	33	16	29	100
Helsingør	Sample	9	42	16	33	100
	Population	23	36	15	26	100
Kolding	Sample	16	35	15	34	100
	Population	24	38	14	25	100
Viborg	Sample	11	43	10	36	100
	Population	26	37	13	24	100

Table SM 4: Household size and distribution of Danish households per housing type

Parameters	Single-family house (SFHA)	Multi-family house (MFSA)	Denmark (DK)
Distribution (%)	60[aj]	40[aj]	100
Average household size (Number of person per household)	1.89	1.66	1.70[b]

Source: (Statistics Denmark, 2015)

The average amount per household in Denmark is: $M_{DK}(Household) = aiM_{SFHA} + ajM_{MFHA}$; $M_{DK}(Person) = bM_{DK}(Household)$

Table SM 5: Distribution of Danish household's size in the single-family household area

Household size (Number of person per households)	1	2	3	4+
Single-family households (SFHA)	27[cj]	38[cj]	14[cj]	22[cj]

Source: (Statistics Denmark, 2015)

The average amount per household in Denmark is: $\mathrm{M}_{\mathrm{SFHA}} = \sum_{k=1}^{n} \mathrm{c}_k \mathrm{m}_{\mathrm{SFHA}(k)}$

Where ck is the distribution according to housing size, and m_{SFHA} *is the mass for each housing size.*

Table SM 6: Average food waste composition (wet mass basis) for each housing type and the weighted average for Denmark

Food waste	SFHA[a] (n=4)[c]		MFHA[b] (n=3)[c]		Denmark (Weighted Average)[d]	
	Mean	SD[e]	Mean	SD[e]	Mean	SD[e]
Avoidable food waste	55.6	2.0	57.8	9.8	56.4	3.8
Avoidable processed food waste	16.7	1.4	22.0	5.7	18.7	2.2
Avoidable processed animal-derived food waste	7.8	1.1	8.9	3.0	8.2	1.3
Avoidable processed vegetable food waste	8.9	0.9	13.0	4.8	10.5	1.8
Avoidable unprocessed food waste	38.9	1.4	35.9	8.0	37.7	3.0
Avoidable unprocessed animal-derived food waste	8.3	0.8	7.3	2.3	8.0	1.0
Avoidable unprocessed vegetable food waste	30.6	1.2	28.5	7.7	29.8	2.9
Unavoidable food waste	44.4	2.1	42.2	4.8	43.6	2.2
Unavoidable animal-derived food waste	3.9	0.8	5.2	1.1	4.4	0.6
Unavoidable vegetable food waste	40.6	1.9	37.0	4.7	39.2	2.1
Animal-derived food waste	20.0	1.6	21.4	4.0	20.5	1.7
Vegetable food waste	80.0	2.4	21.4	10.2	79.5	4.0
Avoidable vegetable food waste	38.9	1.5	35.9	9.1	37.7	3.4
Avoidable animal-derived food waste	16.7	1.4	22.0	3.8	18.7	1.6

[a] Single-family house areas
[b] Multi-family house areas
[c] Number of sampling areas (see Table 1)
[d] Weighted average was calculated with 60% single-family houses and 40% multi-family houses (Statistics Denmark, 2015).
[e] Standard deviation quantifies the amount of dispersion of data set, which consists of the average waste values of the municipalities.

Table SM 7: Names of variables and description for logistic regression model

Response variable (Y)	Influencing factors (explanatory)	Description
Y=0 (FWs was not found in the RHW waste bin) Y=1 (FWs was found in the RHW waste bin)	Region (categorical n=2)	Jutland, Zealand
	Municipalities (categorical n=4)	Gladsaxe, Helsingør, Kolding and Viborg
	Household size (categorical n=2)	1 person, 1+persons
	Household size (continuous)	Number of person per household

Table SM 8: Overview of the result from the logistic regression model assessing factors that influence whether a Danish household generate

Potential influential factors	Municipalities	Regions	Composting	Household size	Household size
Type of variables	Categorical	Categorical	Categorical	Categorical	Continuous
Degree of freedom	3	1	1	1	1
Avoidable food waste	Not(Sig)	Not(Sig)	Not(Sig)	Sig***	Sig***
Avoidable processed food waste	Not(Sig)	-	Not(Sig)	Sig*	Sig*
Avoidable processed animal-derived food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Avoidable processed vegetable food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Avoidable unprocessed FW	Not(Sig)	Not(Sig)	Not(Sig)	Sig***	Sig***
Avoidable unprocessed animal-derived food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Avoidable unprocessed vegetable food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Unavoidable food waste	Not(Sig)	Not(Sig)	Not(Sig)	Sig*	Sig*
Unavoidable animal-derived food waste	Not(Sig)	Not(Sig)	Sig***	Sig***	Sig***
Unavoidable vegetable food waste	Not(Sig)	Not(Sig)	Sig*	Sig*	Sig*

*** *Very high significance probability* ($p<0.001$).

** *High significance probability* ($0.001<p<0.1$).

**significance probability* ($0.05<p<0.001$).

Not(Sig) no significance probability ($p>0.05$)..

Table SM 9: Estimated coefficients, 95% confidence interval and statistically significant of the logistic regression that predict the probability of generating food waste in Danish single-family home

Food waste fractions	Household size	OR[a]	Std. error[b]	Confidence interval (95%)		P-value
				Lower	Upper	
Avoidable food waste	Intercept (1 person)	8.5	1.4	4.64	17.45	< 0.001
	2 persons	3.46	1.59	1.38	8.7	0.00747
	<2 persons	22.41	2.19	5.78	147.55	< 0.001
Avoidable processed food wase	Intercept (1 person)	0.94	1.23	0.63	1.4	0.758
	2 persons	3.92	1.28	2.41	6.4	<0.001
	<2 persons	19.33	1.36	10.73	36.06	<0.001
Avoidable animal-derived food waste	Intercept (1 person)	0.48	1.24	0.31	0.74	<0.001
	2 persons	3	1.28	1.86	4.92	<0.001
	<2 persons	10.9	1.3	6.61	18.33	<0.001
Avoidable vegetable processed food waste	Intercept (1 person)	0.67	1.23	0.44	1	0.0529
	2 persons	2.65	1.27	1.66	4.27	<0.001
	<2 persons	7.2	1.28	4.44	11.83	<0.001
NProcpk	Intercept (1 person)	5.79	1.34	3.39	10.65	< 0.001
	2 persons	3.58	1.49	1.63	7.88	0.00136
	<2 persons	16.38	1.79	5.71	58.94	< 0.001
AnNPkr	Intercept (1 person)	1.02	1.23	0.68	1.53	0.918
	2 persons	2.52	1.27	1.57	4.06	<0.001
	<2 persons	4.97	1.28	3.07	8.1	<0.001
VeNPkr	Intercept (1 person)	3.32	1.28	2.1	5.47	<0.001
	2 persons	2.86	1.37	1.54	5.26	<0.001
	<2 persons	28.55	1.75	10.56	99.8	<0.001
UAvoidkr	Intercept (1 person)	18	1.58	8.11	51.09	< 0.001
	2 persons	2.36	1.82	0.68	7.56	0.15146
	<2 persons	10.58	2.33	2.24	74.73	0.00523
AnUkr	Intercept (1 person)	2.52	1.26	1.63	4	< 0.001
	2 persons	2.48	1.33	1.42	4.29	0.00128
	<2 persons	2.98	1.32	1.72	5.12	< 0.001
VeUkr	Intercept (1 person)	10.88	1.45	5.62	24.38	<0.001
	2 persons	2.7	1.63	1	7.06	0.0423
	<2 persons	6.95	1.79	2.26	23.49	<0.001
AnAvoidkr	Intercept (1 person)	1.38	1.23	0.92	2.08	0.125
	2 persons	3.37	1.29	2.04	5.57	<0.001
	<2 persons	10.41	1.34	5.91	18.72	<0.001
VeAvoidkr	Intercept (1 person)	4.94	1.32	2.97	8.76	< 0.001
	2 persons	2.47	1.42	1.23	4.88	0.00955
	<2 persons	25.65	1.9	8.31	112.18	< 0.001
Ankr	Intercept (1 person)	6.92	1.36	3.93	13.34	<0.001
	2 persons	7.18	1.67	2.7	21.16	<0.001
	<2 persons	6.01	1.58	2.46	15.17	<0.001
Vekr	Intercept (1 person)	46.5	2.04	14.73	282.22	<0.001
	2 persons	1.61	2.4	0.22	8.4	0.5845
	<2 persons	8.22	3.42	0.78	177.89	0.0869

[a]:The estimate of the odds ratios.
[b]:The estimate of the standard error
[c]: Transformed (exponential) 95% confidence interval

Table SM 10: Uncertainty analysis for food waste generation (wet mass basis): Bootstrapping regression results for dataset including only household that generated food waste (mass of food waste is higher than zero)

Food waste	Household size	Statistical parameters							
		Wet mass per household per week				Wet mass per person per week			
				95% CI[a]				95% CI[a]	
		original	bootSE[b]	Lower	Upper	original	bootSE[b]	Lower	Upper
Processed FW	(Intercept)	0.356	0.045	0.265	0.446	0.319	0.041	0.240	0.397
	pers2	0.181	0.058	0.064	0.296	-0.066	0.043	-0.148	0.016
	pers3	0.348	0.085	0.183	0.511	-0.076	0.046	-0.164	0.012
	pers4+	0.861	0.077	0.709	1.015	-0.025	0.042	-0.107	0.056
Avoidable animal-derived processed FW	(Intercept)	0.295	0.049	0.201	0.394	0.235	0.049	0.135	0.329
	pers2	-0.014	0.051	-0.116	0.088	-0.106	0.049	-0.200	-0.005
	pers3	0.109	0.065	-0.021	0.234	-0.099	0.051	-0.197	0.005
	pers4+	0.298	0.057	0.182	0.411	-0.090	0.049	-0.184	0.011
Avoidable vegetable processed FW	(Intercept)	0.182	0.024	0.136	0.228	0.168	0.022	0.125	0.210
	pers2	0.195	0.036	0.123	0.263	0.008	0.024	-0.038	0.055
	pers3	0.260	0.053	0.152	0.362	-0.018	0.027	-0.068	0.033
	pers4+	0.468	0.046	0.373	0.557	-0.006	0.023	-0.050	0.040
Avoidable vegetable unprocessed FW	(Intercept)	0.320	0.037	0.246	0.393	0.274	0.037	0.196	0.345
	pers2	0.037	0.042	-0.044	0.122	-0.110	0.039	-0.185	-0.028
	pers3	0.122	0.049	0.026	0.221	-0.125	0.039	-0.200	-0.044
	pers4+	0.144	0.046	0.057	0.235	-0.156	0.038	-0.230	-0.076

[a]:Confidence interval.

[b] The bootstrapped estimates of standard error

Table SM 11: Uncertainty analysis for food waste generation (wet mass basis): Bootstrapping regression results for dataset including both households that generated and not food waste (raw data)

Food waste	Household size	Statistical parameters							
		Wet mass per household per week				Wet mass per person per week			
				95% CI[a]				95% CI[a]	
		original	bootSE[b]	Lower	Upper	original	bootSE[b]	Lower	Upper
Processed FW	(Intercept)	0.168	0.028	0.114	0.221	0.125	0.024	0.076	0.172
	pers2	0.233	0.040	0.155	0.314	0.060	0.025	0.011	0.110
	pers3	0.455	0.069	0.325	0.586	0.089	0.029	0.031	0.146
	pers4+	0.988	0.071	0.853	1.123	0.151	0.026	0.101	0.204
Avoidable animal-derived processed FW	(Intercept)	0.067	0.015	0.036	0.096	0.045	0.010	0.026	0.063
	pers2	0.063	0.018	0.028	0.099	0.020	0.010	0.001	0.040
	pers3	0.166	0.032	0.100	0.227	0.046	0.013	0.019	0.074
	pers4+	0.408	0.037	0.338	0.481	0.073	0.011	0.051	0.096
Avoidable vegetable processed FW	(Intercept)	0.071	0.012	0.046	0.097	0.059	0.011	0.038	0.080
	pers2	0.140	0.024	0.091	0.188	0.044	0.013	0.018	0.070
	pers3	0.220	0.036	0.150	0.291	0.048	0.016	0.016	0.080
	pers4+	0.438	0.040	0.356	0.517	0.077	0.013	0.052	0.103
Avoidable vegetable unprocessed FW	(Intercept)	0.149	0.024	0.103	0.195	0.111	0.020	0.073	0.151
	pers2	0.090	0.028	0.033	0.144	0.005	0.019	-0.034	0.043
	pers3	0.187	0.039	0.109	0.262	0.009	0.021	-0.034	0.049
	pers4+	0.219	0.034	0.149	0.285	-0.009	0.019	-0.048	0.027

[a]:Confidence interval.

[b]The bootstrapped estimates of standard error

Table SM 12: Comparison between datasets containing or not households that generated food. Difference is between dataset (raw dataset, including household with zero food waste) and dataset including only households that generated food waste.

Food waste fractions	Difference	Bias	5%	95%	Significance
Food waste	-0.022	0.005	-0.289	0.232	
Avoidable food waste	-0.071	0.002	-0.262	0.105	
Avoidable processed food waste	-0.161	-0.001	-0.241	-0.072	*
Avoidable processed animal-derived food waste	-0.168	0.000	-0.215	-0.121	*
Avoidable processed vegetable food waste	-0.176	0.000	-0.232	-0.121	*
Avoidable unprocessed food waste	-0.072	0.002	-0.202	0.074	
Avoidable unprocessed animal-derived food waste	-0.130	0.000	-0.188	-0.074	*
Avoidable unprocessed vegetable food waste	-0.101	0.000	-0.220	0.032	
Unavoidable food waste	-0.035	-0.001	-0.158	0.089	
Unavoidable animal-derived food waste	-0.036	-0.001	-0.065	-0.006	*
Unavoidable vegetable food waste	-0.016	-0.001	-0.138	0.098	

**significance probability (0.05<p<0.001).*

Not(Sig) no significance probability (p>0.05).

Supplementary materials- Figures

Figure SM 1: Percentage of households that did not generate food waste (“no”) in the single-family house area (% n/n) A: Avoidable and unavoidable; B Avoidable animal-derived and avoidable vegetable; C: Animal derived and vegetable food waste; D: Avoidable processed and avoidable unprocessed.

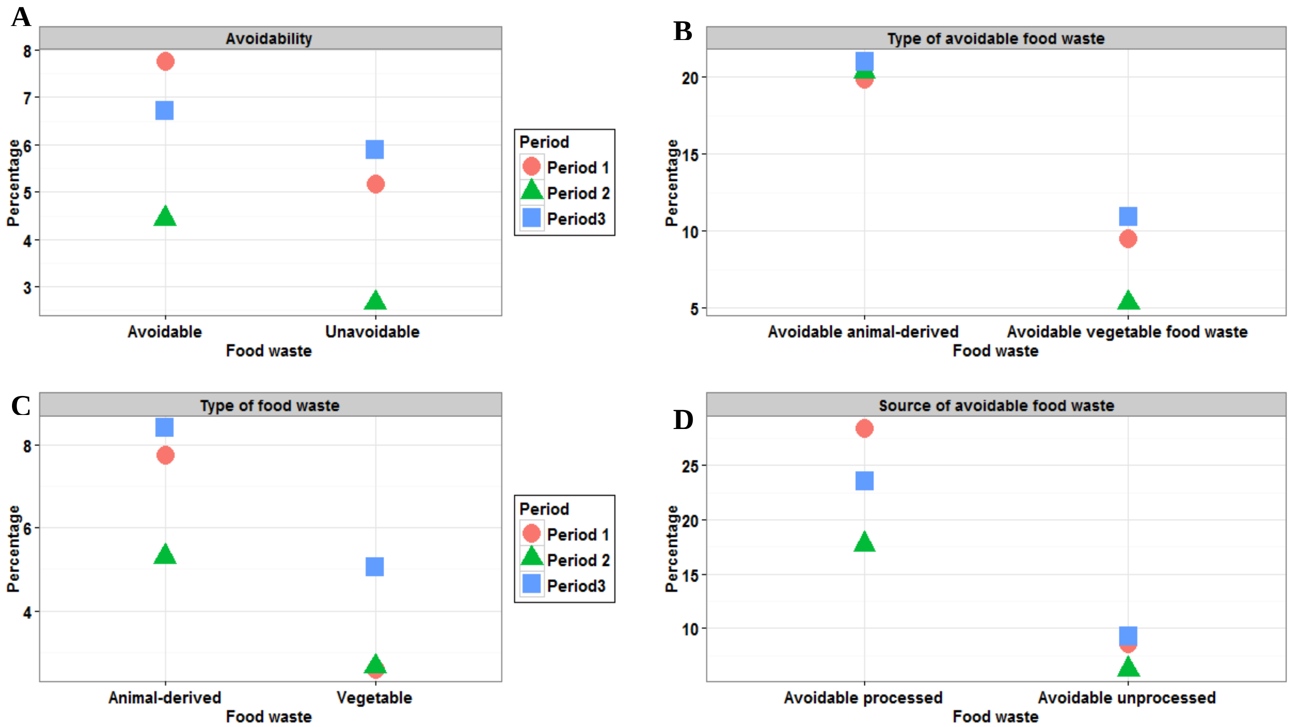

Figure SM 2: Summary of the distribution of total food waste (wet mass basis) among single-family houses as function of household size based on kg per household per week and kg per person per week

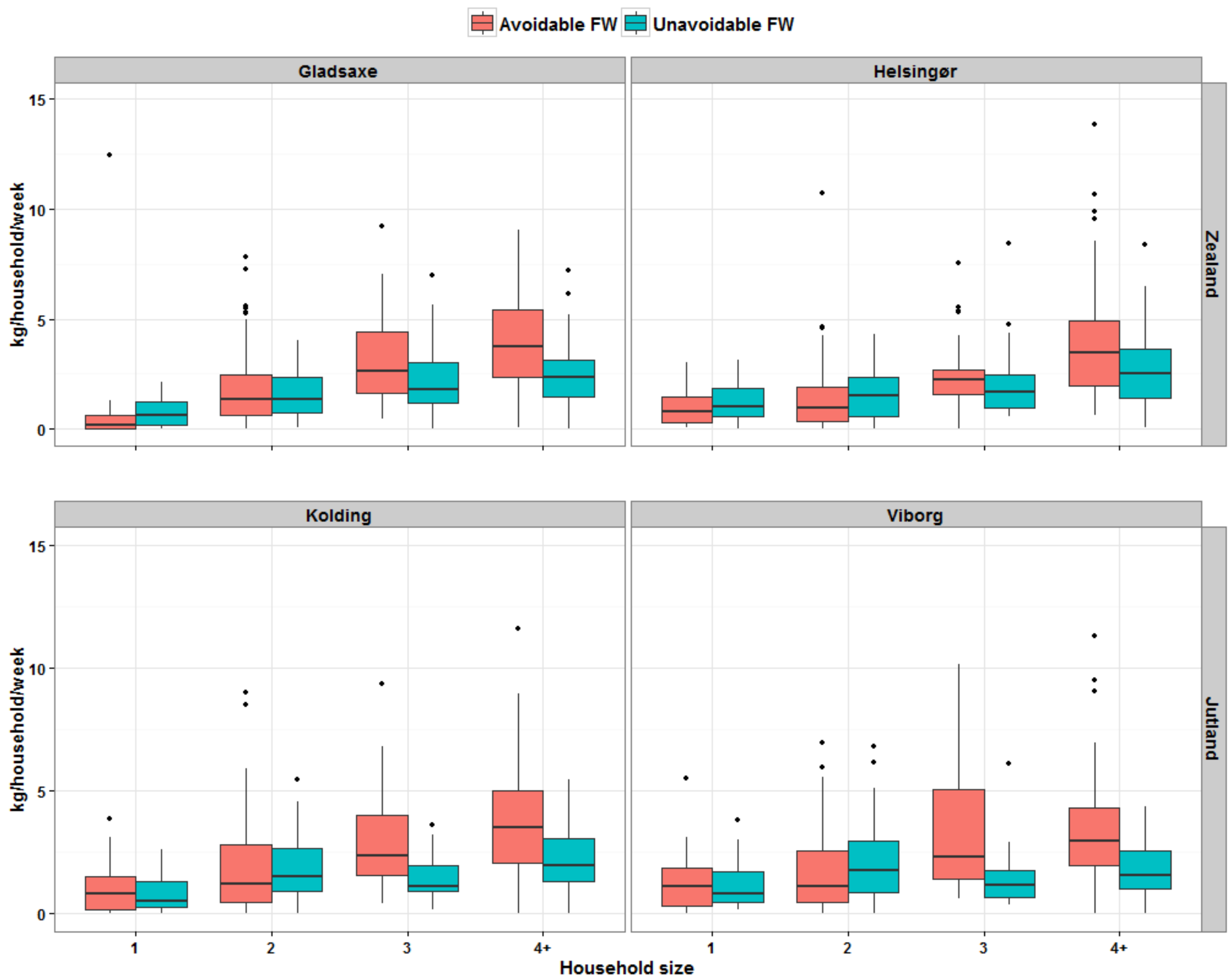

Figure SM 3: Percentage of households that did not generate food waste (“no”) in the single-family house area (% n/n): total food waste and other residual household waste

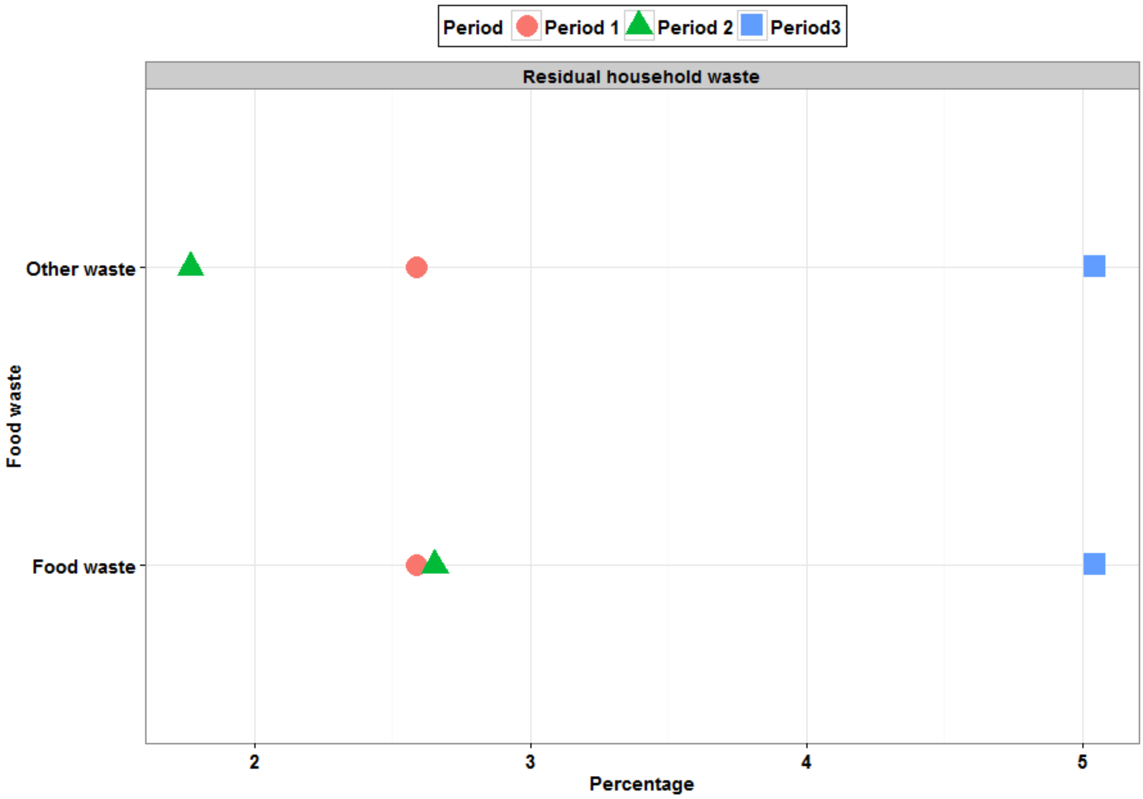

Figure SM 4: Percentage of households that did not generate food waste ("no") in the single-family house area (% n/n) for the six food waste fractions

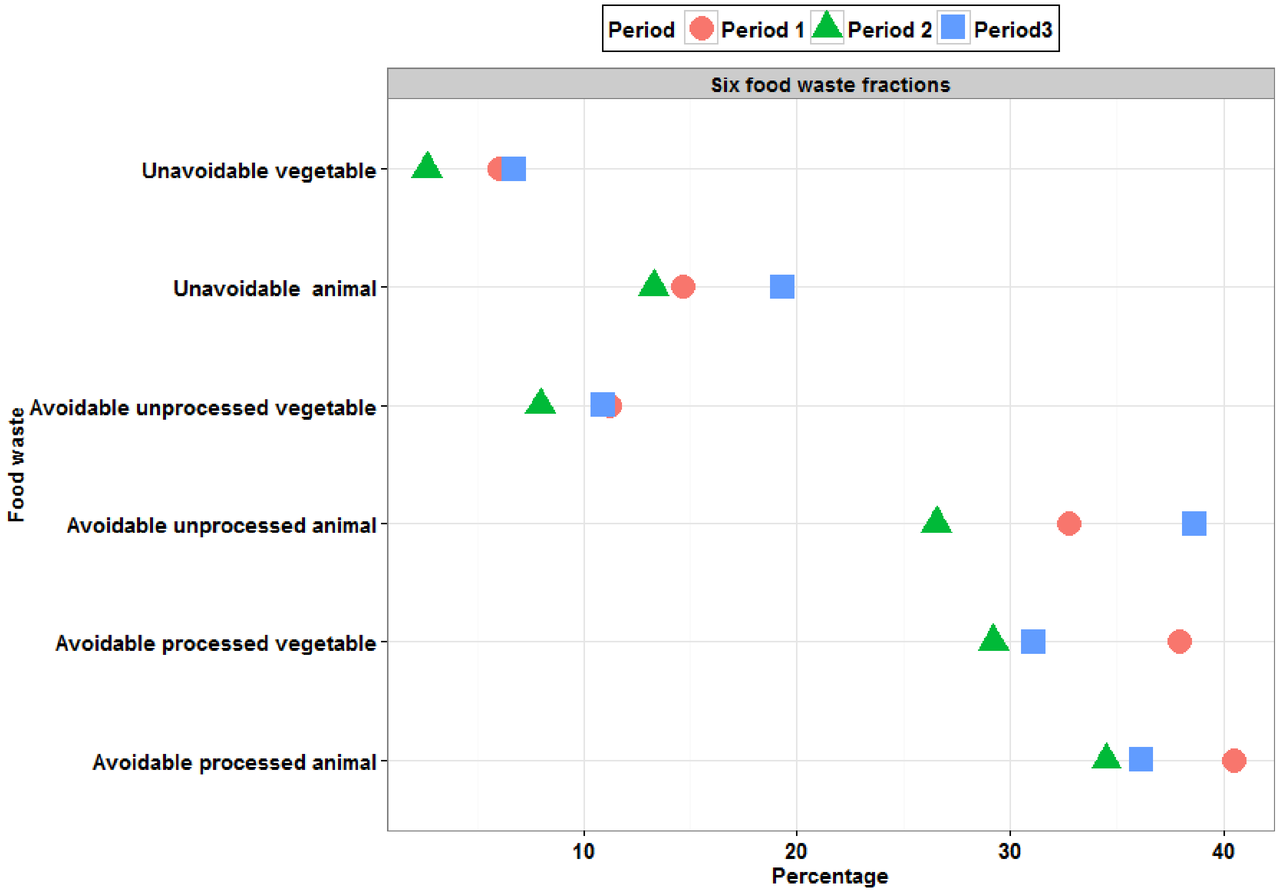

Figure SM 5: Summary of the distribution of total food waste (wet mass basis) among households as function of household size based on kg per household per week and kg per person per week